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Salt Spray Test to Determine Galvanic Corrosion Levels of Electroless Nickel Connectors Mounted on an Aluminum Bracket

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May 2014

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LIST OF ACRONYMS AND SYMBOLS

DWV	dielectric withstanding voltage
EN	electroless nickel
GSE	ground support equipment
IR	insulation resistance
MSFC	Marshall Space Flight Center
SEM	scanning electron microscopy
ZN	zinc-nickel

TECHNICAL MEMORANDUM

SALT SPRAY TEST TO DETERMINE GALVANIC CORROSION LEVELS OF ELECTROLESS NICKEL CONNECTORS MOUNTED ON AN ALUMINUM BRACKET

1. INTRODUCTION

For decades, NASA has flown electroless nickel- (EN) coated aluminum connectors mounted to aluminum chassis and brackets. This mounting scenario has also been used in ground support equipment (GSE) at Kennedy Space Center, where a known salt atmosphere exists. In many cases, the GSE exposure to these environments has been several days. Marshall Space Flight Center (MSFC) engineers are not aware of any galvanic corrosion issues due to GSE or flight connectors despite long-term exposure to these harsh environments. Unfortunately, these observations have never been officially documented in any report. Additionally, galvanic corrosion charts and series tables (e.g., MIL-STD-889B)[1] show that aluminum-to-nickel contact forms a galvanic couple when the nickel-to-aluminum interface is exposed to aqueous halide environments. These charts and the lack of actual test data forced engineers to consider zinc-nickel (ZN) when the new corrosion certification, NASA-STD-6012, increased the certification time from 48 hr to 168 hr.[2] One military standard relied upon, namely MIL-DTL-38999, indicates that class F series EN connectors are certified to 48 hr, whereas ZN is certified to 168 hr.[3] Because EN connectors were only certified to 48 hr, ZN connectors were an obvious replacement. However, MSFC has no flight history with ZN. Additionally, zinc and zinc alloys are prohibited per MSFC-STD-3012 due to possible vacuum sublimation.[4] There is also evidence that zinc alloy plating may grow zinc whiskers, which is an electrical shorting concern.[5] This meant that a significant amount of testing and cost increases were on the horizon to qualify the ZN material. To avoid these issues, a decision was made to purchase several MIL-DTL-38999[3] class F, EN-coated aluminum connectors using a typical flight procurement process, mount them to an alodined aluminum bracket, and expose them to a 168-hr salt spray environment. Two pass/fail criteria were established: (1) Post-test connectors must meet the 2.5-mΩ, class R bonding requirement per NASA-STD-4003A[6] and (2) post-test connectors must not show excessive pitting and flaking that would result in mechanical failure of the connector.

2. PROCEDURE

Four mated pairs of class F connectors were used in the test. The connectors were randomly selected such that there were multiple manufacturers with various lot date codes. The connector selection process was purposely chosen this way to account for the randomness in the procurement cycle, that is, to represent what actual flight hardware would consist of in a real manufacturing environment. The connector part numbers used for this test are listed in table 1. The reference designators were assigned by the testing organization for identification purposes.

Table 1. MIL-DTL-38999[3] class F, EN-coated aluminum connector part number and test article assembly identification table.

Description	Item	Receptacle	Plug
Connector assembly 1	In-house reference No.	J11	P11
	Connector part No.	D38999/24FF35PN	D38999/26FF35SN
	Backshell part No.	M85049/38S19N	M85049/38S19N
Connector assembly 2	In-house reference No.	J12	P12
	Connector part No.	D38999/24FC35SA	D38999/26FC35PA
	Backshell part No.	M85049/38S13N	M85049/38S13N
Connector assembly 3	In-house reference No.	J13	P13
	Connector part No.	D38999/20FF35SN	D38999/26FF35PN
	Backshell part No.	M85049/38S19N	M85049/38S19N
Connector assembly 4	In-house reference No.	J14	P14
	Connector part No.	D38999/24FJ35PN	D38999/26FJ35SN
	Backshell part No.	M85049/38S25N	M85049/38S25N

Note: The in-house reference number was assigned by the testing lab and used to designate the connector assembly location on the aluminum bracket.

To simulate an actual flight configuration, flight-like cable assemblies were fabricated by a certified technician. Electrical acceptance tests, including electrical continuity and bonding, insulation resistance (IR), and dielectric withstanding voltage (DWV) per NASA-STD-8739.4[7] and electrical bonding checks per NASA-STD-4003A,[6] were performed. Electrical continuity measurements were made with a calibrated Fluke 189 True RMS multimeter. Insulation resistance and DWV tests were conducted with a calibrated Slaughter Hipot Tester. Electrical bonding measurements were made with a Keithley 580 micro-ohmmeter. Each connector was wired with six crimped contacts using three two-conductor cables. The cables were identifiable by part number M27500-22RE 2N06. Each wire was inserted in a row of the connector, and each unused cavity was sealed with a contact and a sealing plug. Contact retention tests were performed to ensure contacts were locked into place. Backshells were installed onto each connector and are identifiable by part number M85049/38SXXN. The ‘XX’ placeholder in the backshell part number is dependent upon the

shell size of the connector used. The connectors and corresponding backshell part numbers used in this test are detailed in table 1.

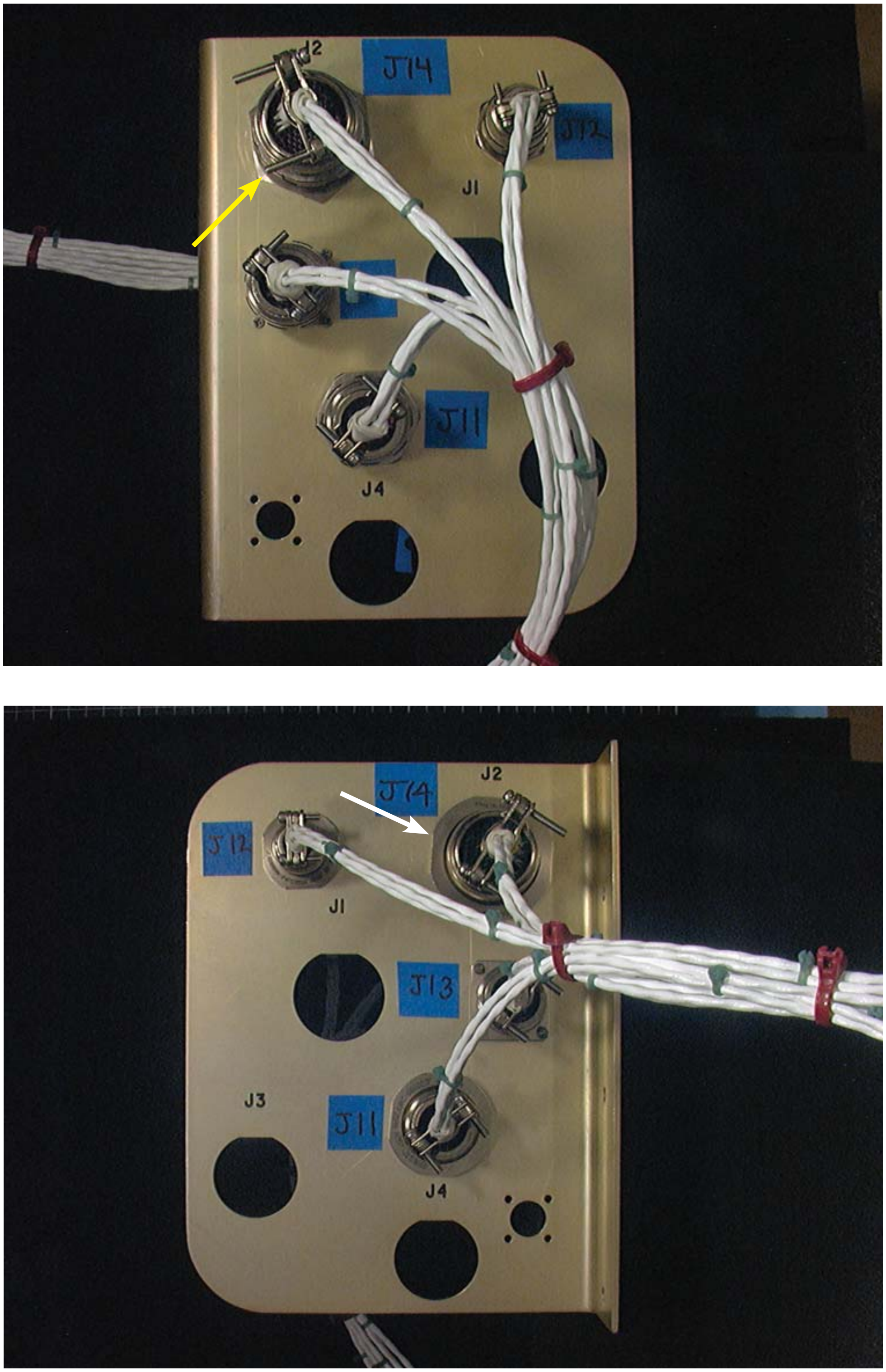
Each receptacle connector assembly was then mounted to the bracket with either a jam nut (J11, J12, and J14) or mounting screws (J13). Each jam nut and fastener was tightened to flight-qualified torque values as specified in MIL-DTL-38999.[3] All connector plugs were completely mated to their respective receptacles. The connectors were mounted to a bracket made from 6061-T6 aluminum plate. Before connector mounting, the bracket was alodined per chemical conversion coating specification MIL-DTL-5541.[8] For purposes of this Technical Memorandum, the completed cable assembly and alodined aluminum bracket will be referred to as the 'test article.'

3. ANALYSIS

As-received photos of the presalt spray test article are shown in figure 1. Detailed photographs of the plugs and receptacles were taken at the interface between the connector and bracket. These photos are shown in figures 2 and 3. The inspection revealed slight manufacturing marks and scratches noted on both the connectors and the mounting bracket. However, no exposed aluminum was evident on the connectors or at the mating interface. These conditions are typically found during chassis builds and are not rejectable per commonly used workmanship standards.

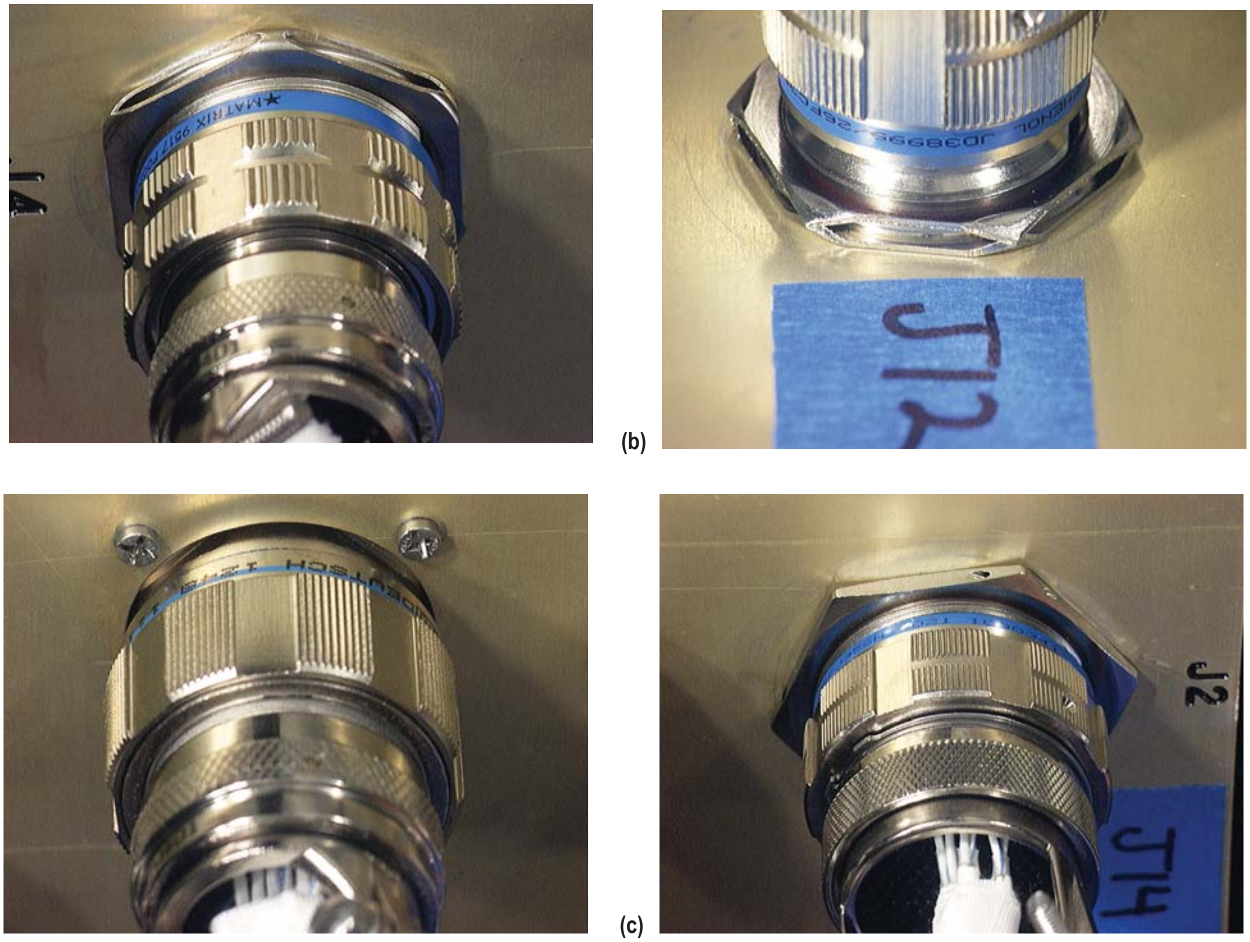
Electrical continuity tests were performed to measure wire and socket/pin engagement. The data showed a nominal resistance of ≈0.2 Ω. Insulation resistance tests were performed between each conductor and all other conductors as well as between each conductor and connector shell/bracket. Insulation resistance was >1,000 MΩ at an applied voltage of 500 ± 50 VDC for a minimum of 30 s. The NASA-STD-8739.4 requirement is 100 MΩ; therefore, all IR tests met the requirement.[7] DWV tests were performed by applying 1,500 VDC to each conductor and all other conductors in each of the harness assemblies and each conductor and connector shell/bracket. Leakage current was found to be <30 µA. NASA-STD-8739.4 specifies leakage current to be <1 mA; therefore, all DWV tests met the requirement.[7] Electrical measurement data from these tests are shown in table 2.

Presalt spray electrical bonding measurements were also performed using a four-probe Kelvin method and a calibrated micro-ohmmeter. Per requirements in NASA-STD-4003A, the electrical resistance must not exceed 2.5 mΩ.[6] Table 3 contains data from the measurements. The data clearly show that all bonding measurements meet the requirement.



(a)
(b)

Figure 1. Test article assembly setup: (a) Overall plug side view and (b) overall receptacle side view. Plugs are differentiated from receptacles by a coupling nut mated to the jam nut receptacle (yellow arrow). Receptacles are differentiated from plugs by a flange (white arrow).



(a) (b) (c) (c)

Figure 2. Close-up views of the four plugs' coupling nuts at the interface between the plug connector and the receptacle connector prior to salt spray testing: (a) P11, (b) P12, (c) P13, and (d) P14.

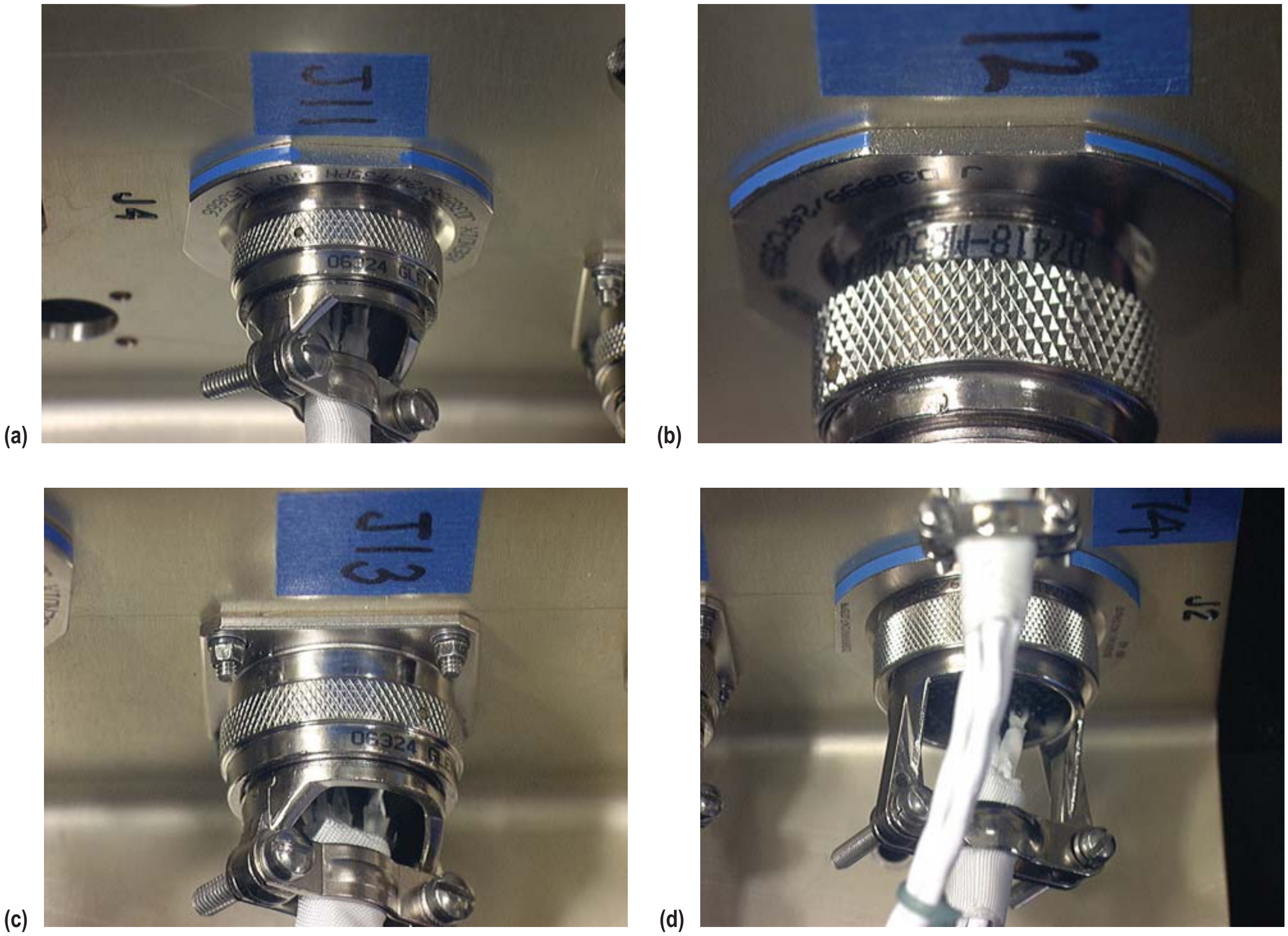


Figure 3. Each of the four receptacles at the interface between the connector flange and the bracket prior to salt spray testing: (a) J11, (b) J12, (c) J13, and (d) J14.

Table 2. Electrical continuity test results—baseline and after removal from bath (pre- and post-168-hr salt spray test).

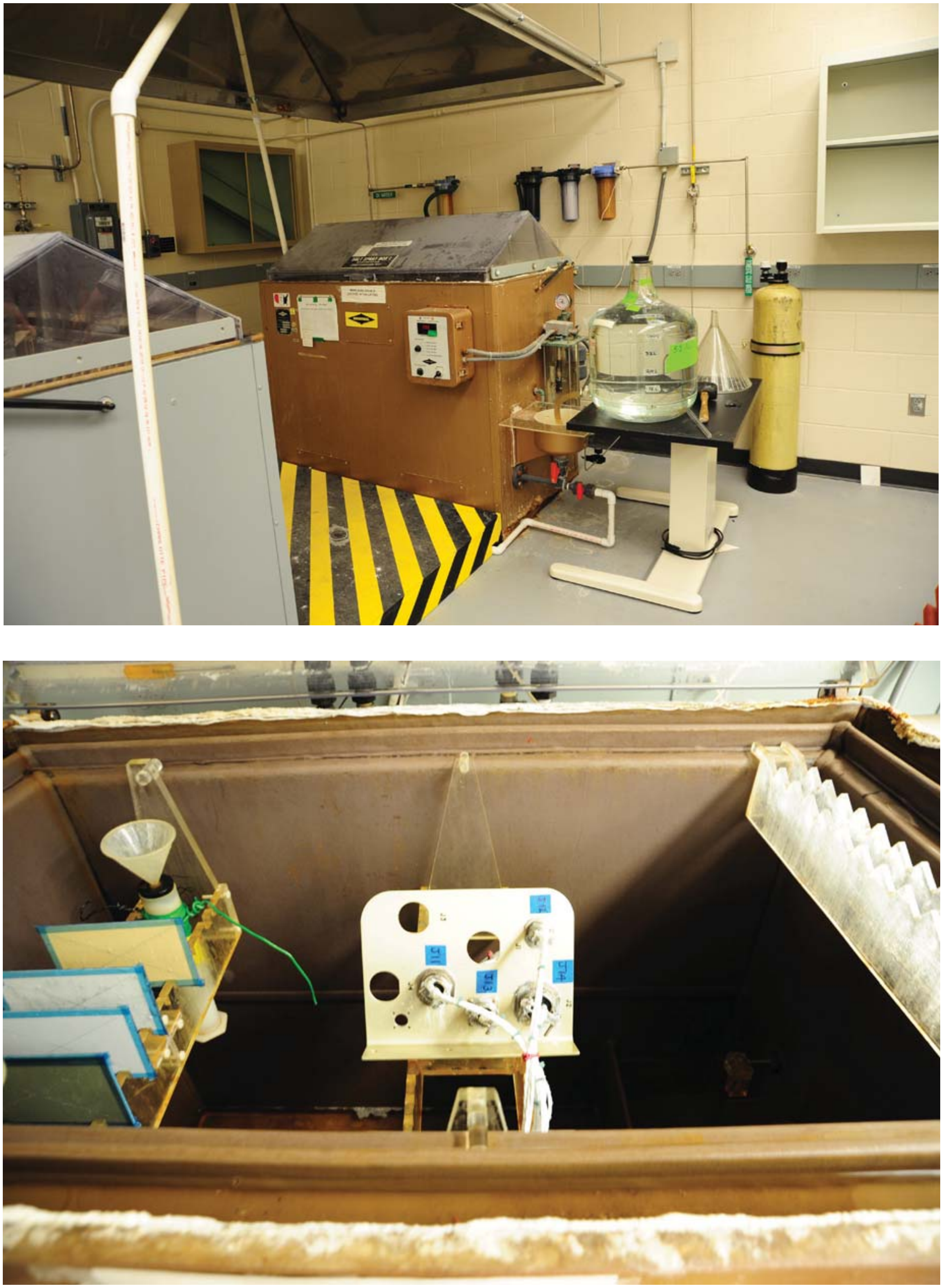
Presalt Spray		**Postsalt Spray**	
J11/P11		J11/P11	
Wire 1 top white	0.24 mΩ	Wire 1 top white	0.20 mΩ
Wire 1 top white/blue	0.19 mΩ	Wire 1 top white/blue	0.19 mΩ
Wire 2 top white	0.21 mΩ	Wire 2 top white	0.21 mΩ
Wire 2 top white/blue	0.22 mΩ	Wire 2 top white/blue	0.20 mΩ
Wire 3 top white	0.21 mΩ	Wire 3 top white	0.21 mΩ
Wire 3 top white/blue	0.23 mΩ	Wire 3 top white/blue	0.21 mΩ
J12/P12		J12/P12	
Wire 1 top white	0.23 mΩ	Wire 1 top white	0.23 mΩ
Wire 1 top white/blue	0.19 mΩ	Wire 1 top white/blue	0.20 mΩ
Wire 2 top white	0.19 mΩ	Wire 2 top white	0.22 mΩ
Wire 2 top white/blue	0.20 mΩ	Wire 2 top white/blue	0.22 mΩ
Wire 3 top white	0.20 mΩ	Wire 3 top white	0.20 mΩ
Wire 3 top white/blue	0.19 mΩ	Wire 3 top white/blue	0.20 mΩ
J13/P13		J13/P13	
Wire 1 top white	0.23 mΩ	Wire 1 top white	0.23 mΩ
Wire 1 top white/blue	0.21 mΩ	Wire 1 top white/blue	0.22 mΩ
Wire 2 top white	0.21 mΩ	Wire 2 top white	0.20 mΩ
Wire 2 top white/blue	0.21 mΩ	Wire 2 top white/blue	0.21 mΩ
Wire 3 top white	0.22 mΩ	Wire 3 top white	0.21 mΩ
Wire 3 top white/blue	0.20 mΩ	Wire 3 top white/blue	0.21 mΩ
J14/P14		J14/P14	
Wire 1 top white	0.21 mΩ	Wire 1 top white	0.20 mΩ
Wire 1 top white/blue	0.22 mΩ	Wire 1 top white/blue	0.22 mΩ
Wire 2 top white	0.21 mΩ	Wire 2 top white	0.21 mΩ
Wire 2 top white/blue	0.20 mΩ	Wire 2 top white/blue	0.20 mΩ
Wire 3 top white	0.21 mΩ	Wire 3 top white	0.21 mΩ
Wire 3 top white/blue	0.22 mΩ	Wire 3 top white/blue	0.22 mΩ

Table 3. Electrical bonding measurement test results—baseline (pre-168-hr salt spray test).

J11 to Bracket		P11 to Bracket	
Flange	0.13 mΩ	Coupling nut	0.87 mΩ
J12 to Bracket		P12 to Bracket	
Flange	0.09 mΩ	Coupling nut	0.25 mΩ
J13 to Bracket		P13 to Bracket	
Flange	0.48 mΩ	Coupling nut	0.42 mΩ
J14 to Bracket		P14 to Bracket	
Flange	0.11 mΩ	Coupling nut	0.82 mΩ

After the electrical testing, each end of the wire pigtails were wrapped with duct tape to prevent moisture from wicking up the wire insulation during salt spray testing. The test article was then taken to the salt spray test facility (P.D. Torres and D.D. Jones, NASA internal memo, “Salt Fog Test of Electrical Connectors for the Space Launch System,” 2013). The test article was subjected to the salt test per ASTM B117-11 for 168 hr continuously.[9] The chamber used is shown in figure 4.

Upon completion of the salt exposure test, the test article was photographed (fig. 4(b)). The test article was then removed from the chamber, and images were taken immediately to document the postsalt spray condition of the test article. These images are shown in figures 5–7. Following photography, postsalt spray electrical bonding measurements were performed at various locations across the connector assembly and backshells to verify conformance to the class R bonding requirements of NASA-STD-4003A of <2.5 mΩ.[6] All bonding measurements met this requirement and passed the first criteria. Test results from these bonding measurements are shown in table 4.

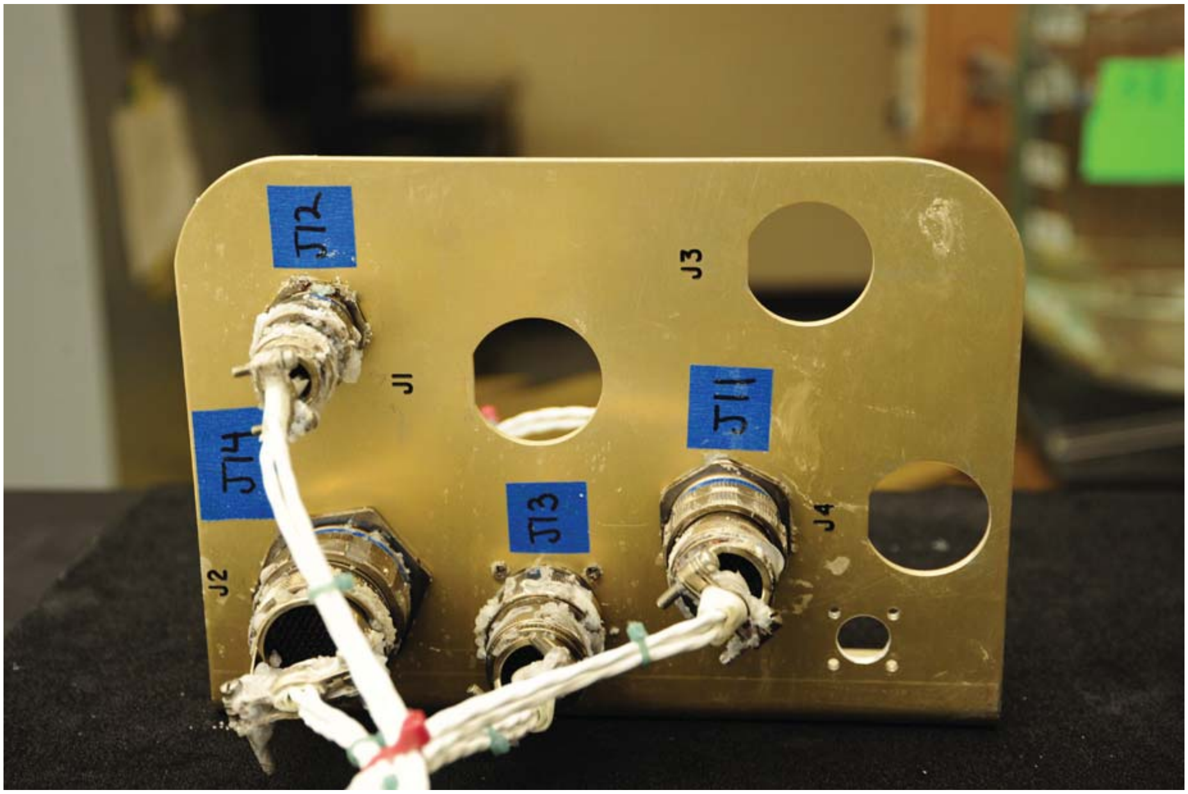


(a)

(b)

Figure 4. Salt spray test equipment configuration: (a) Salt spray test equipment and (b) test article after testing but prior to removal from the chamber.

(a)



(b)

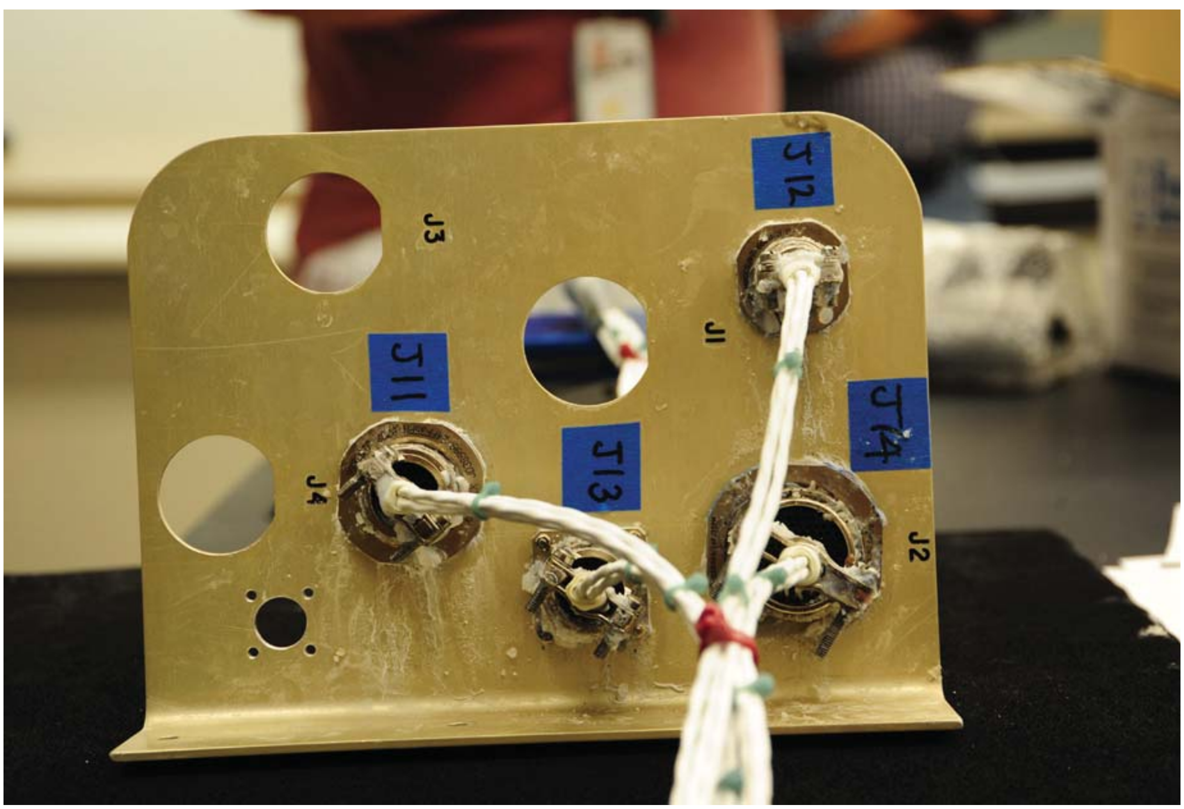


Figure 5. Test article immediately after removal from the salt spray test chamber: (a) Overall plug side and (b) overall receptacle side of the assembly.

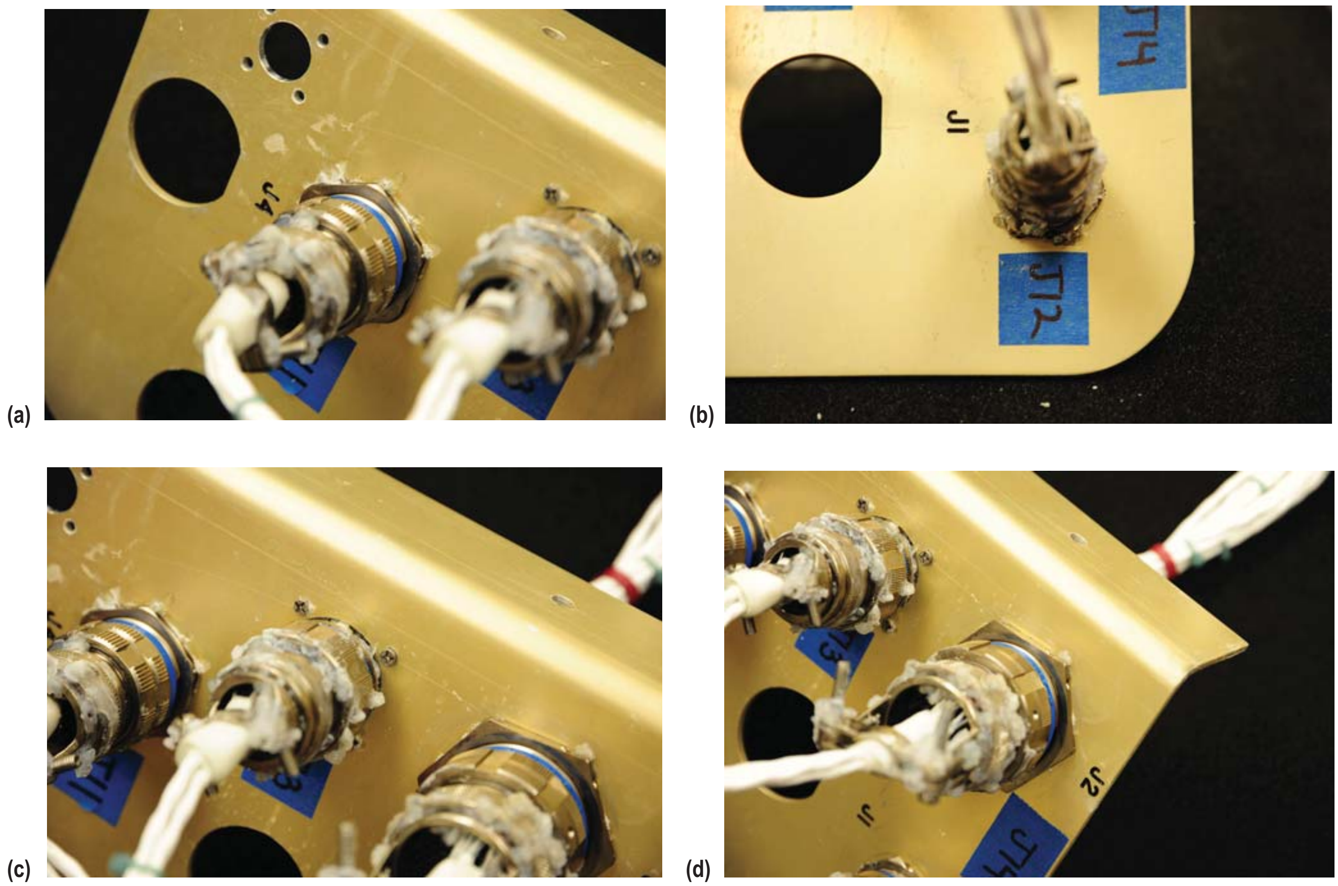


Figure 6. Each of the four plugs at the interface between the plug connector and the receptacle connector after removal from the salt spray test chamber: (a) P11, (b) P12, (c) P13, and (d) P14.

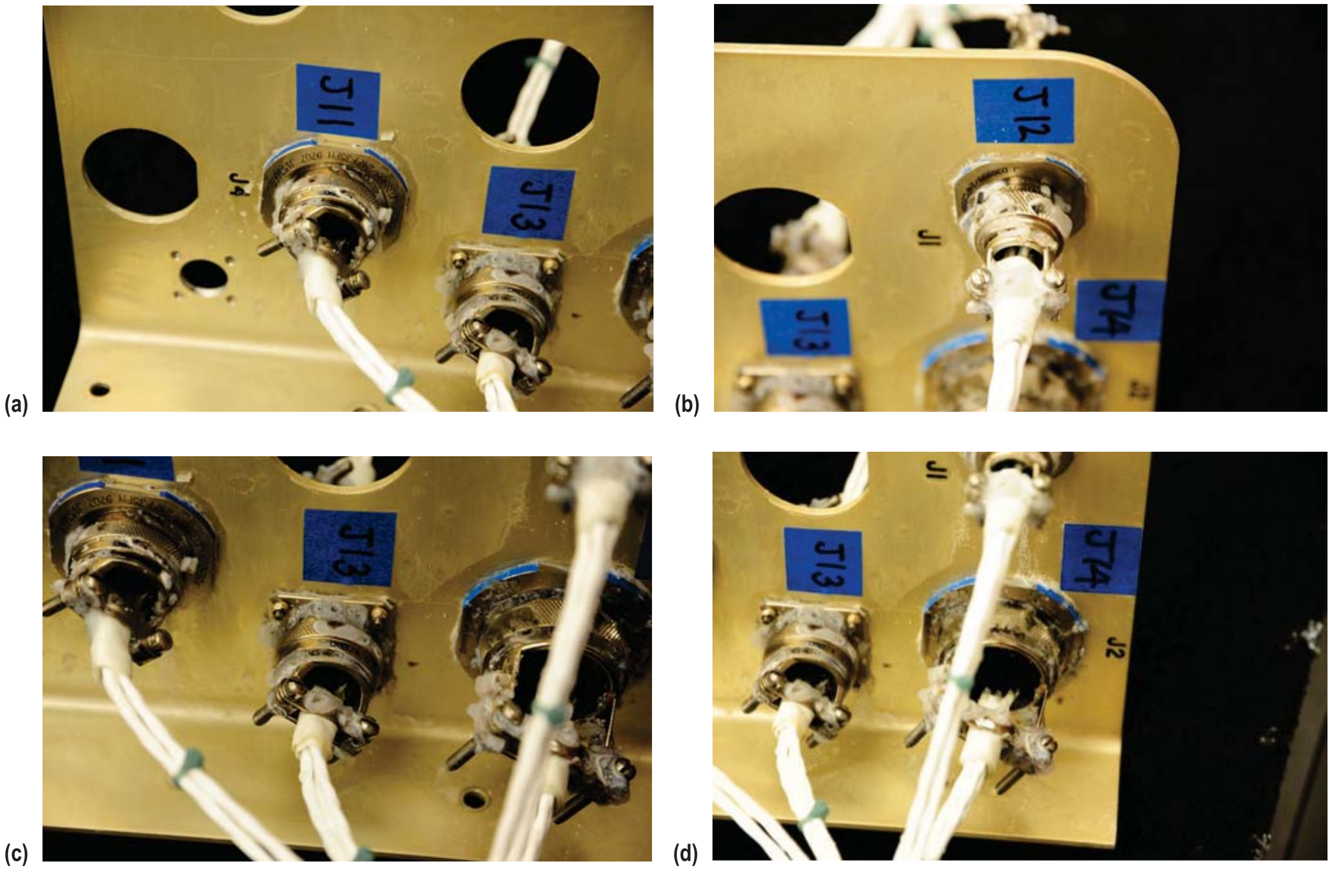


Figure 7. Each of the four receptacles at the interface between the connector flange and the bracket after removal from the salt spray test chamber: (a) J11, (b) J12, (c) J13, and (d) J14.

Table 4. Electrical bonding measurement test results—after removal from bath (post-168-hr salt spray test).

J11 to Bracket		P11 to Bracket	
Flange	0.32 mΩ	Jam nut	0.26 mΩ
Body	0.21 mΩ	Coupling nut	0.15 mΩ
Backshell	0.22 mΩ	Backshell	0.11 mΩ
J11 to P11 Backshell-to-backshell	0.13 mΩ		
J12 to Bracket		P12 to Bracket	
Flange	0.31 mΩ	Jam nut	0.32 mΩ
Body	0.28 mΩ	Coupling nut	0.21 mΩ
Backshell	0.28 mΩ	Backshell	0.15 mΩ
J12 to P12 Backshell-to-backshell	0.15 mΩ		
J13 to Bracket		P13 to Bracket	
Flange	0.39 mΩ	Mounting screw	0.34 mΩ
Body	0.43 mΩ	Coupling nut	0.77 mΩ
Backshell	0.43 mΩ	Backshell	0.68 mΩ
J13 to P13 Backshell-to-backshell	0.03 mΩ		
J14 to Bracket		P14 to Bracket	
Flange	0.31 mΩ	Jam nut	0.24 mΩ
Body	0.15 mΩ	Coupling nut	0.36 mΩ
Backshell	0.16 mΩ	Backshell	0.28 mΩ
J14 to P14 Backshell-to-backshell	0.30 mΩ		

The test article was spot rinsed and dried in ambient air for three days. As can be seen in figures 8 and 9, residual salt deposits remained on the test article. Electrical bonding measurements were taken again at various locations across the connector assembly and backshell to verify conformance to the class R bonding requirements. Again, all connectors met the <2.5-mΩ requirement. These test results are given in table 5. Electrical continuity, IR, and DWV were also retested to verify internal connector integrity. Electrical continuity test data were consistent with prespray data and showed a nominal resistance of ≈0.2 Ω. All IR and DWV test results met the specified requirements. Results of these electrical tests are listed in table 2.

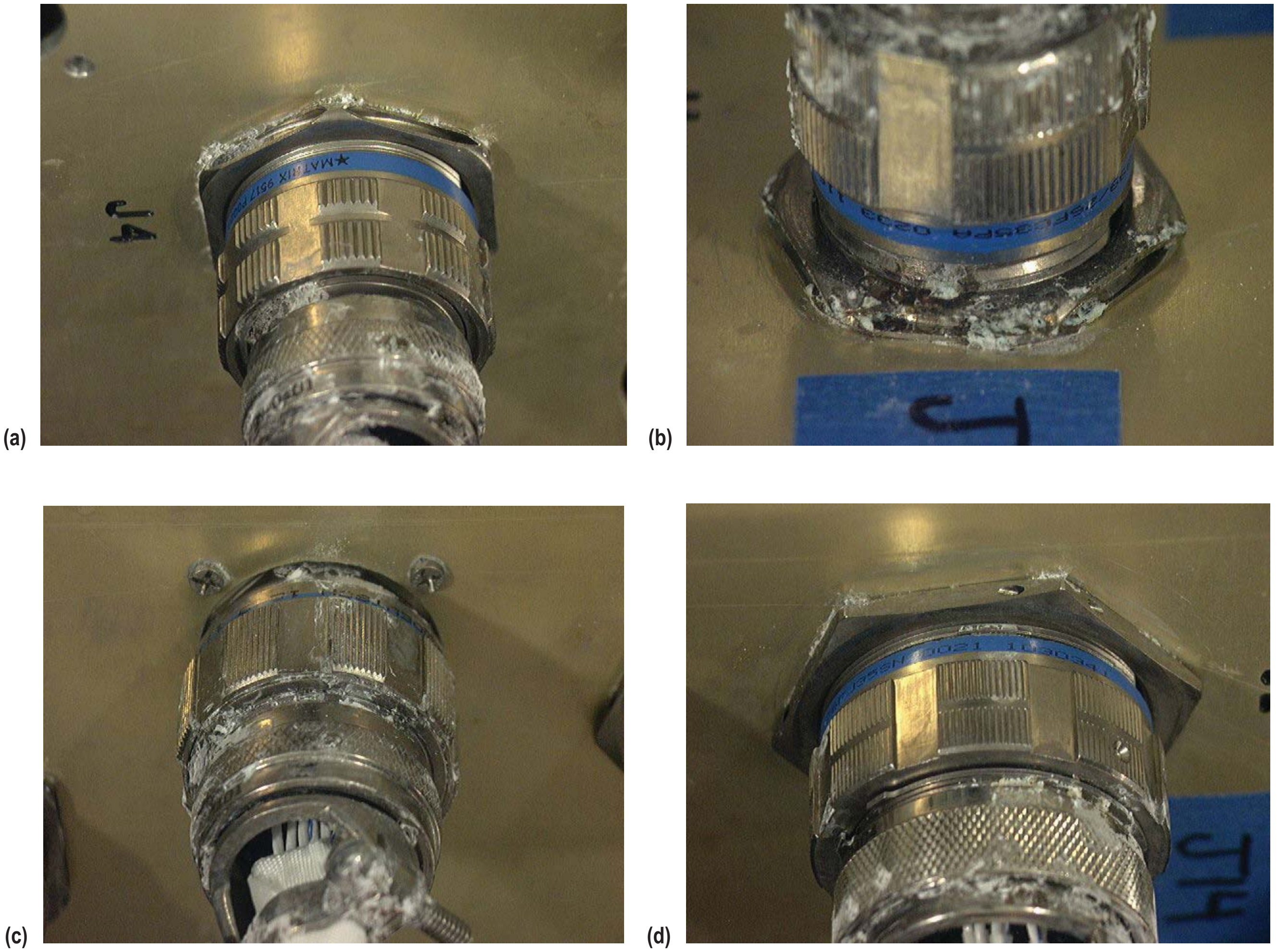


Figure 8. Each of the four plugs at the interface between the connector and the receptacle connector after cleaning: (a) P11, (b) P12, (c) P13, and (d) P14. As can be seen in the images, salt deposits remained on the test article after cleaning.

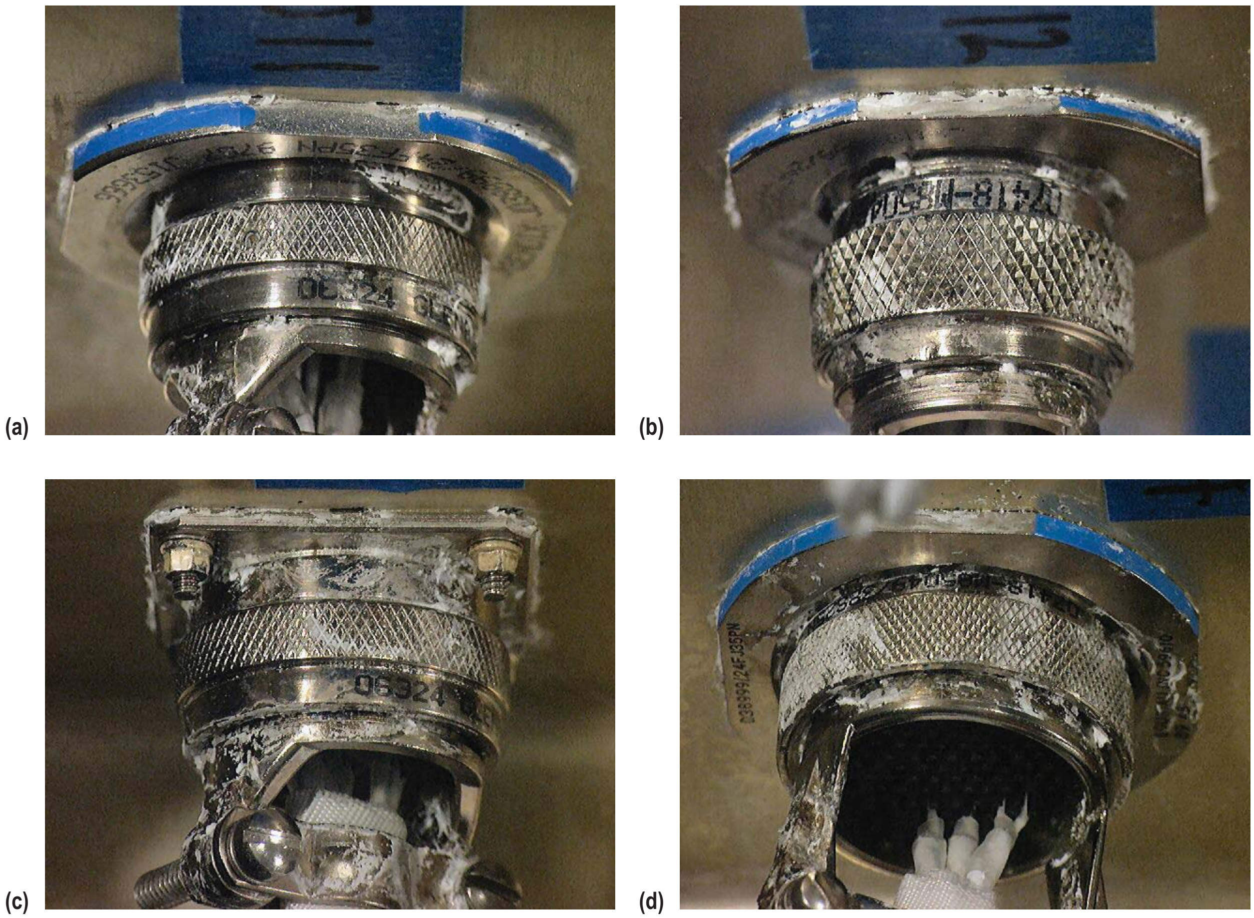
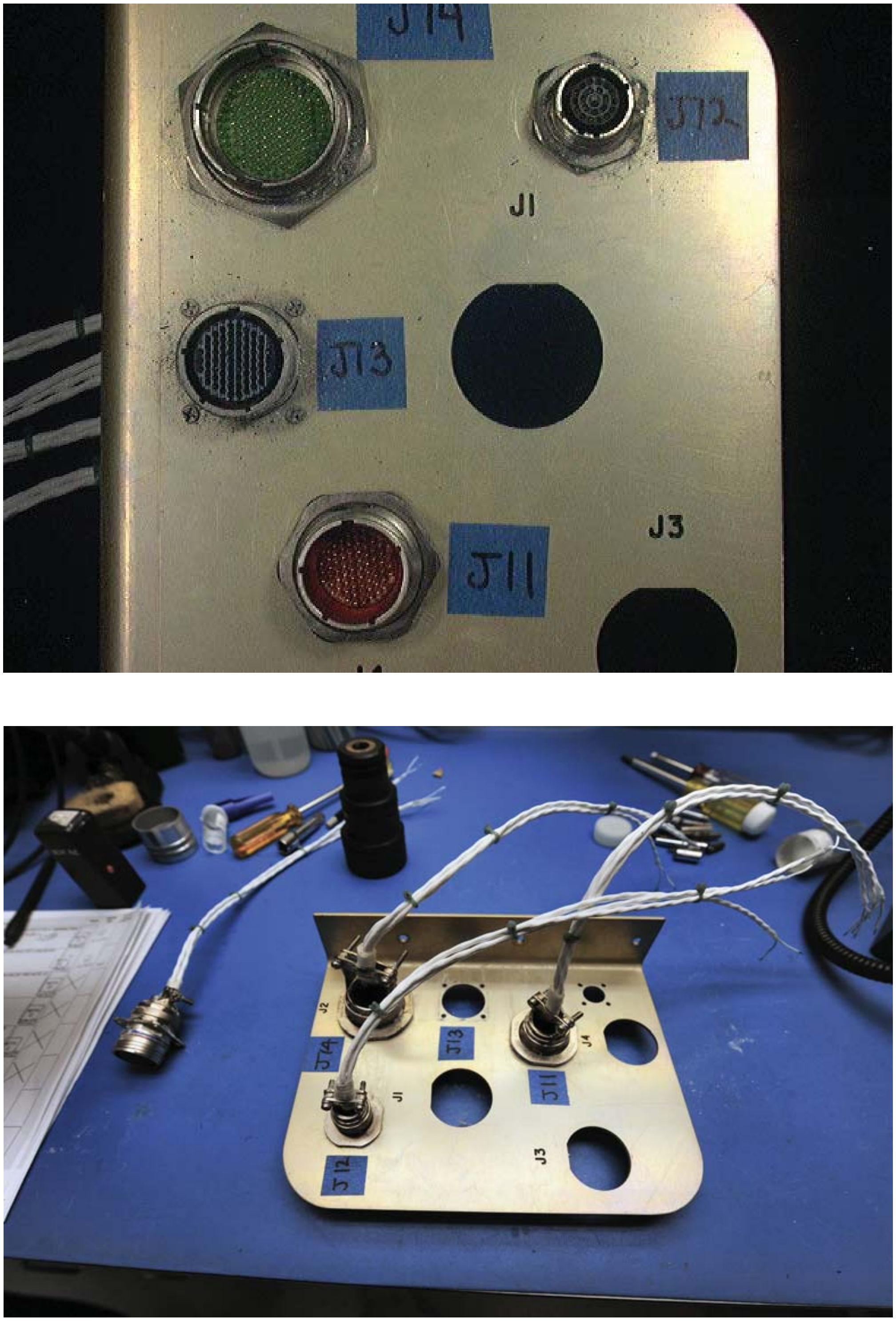


Figure 9. Each of the four receptacles at the interface between the connector flange and the bracket after cleaning: (a) J11, (b) J12, (c) J13, and (d) J14. Salt deposits remained on the test article after cleaning.

Table 5. Electrical bonding measurement test results—after removal from bath, cleaning, and three-day wait (post-168-hr salt spray test and clean).

J11 to Bracket		P11 to Bracket	
Flange	0.05 mΩ	Jam nut	0.11 mΩ
Body	0.17 mΩ	Coupling nut	0.66 mΩ
Backshell	0.17 mΩ	Backshell	0.34 mΩ
J11 to P11 Backshell-to-backshell	0.43 mΩ		
J12 to Bracket		P12 to Bracket	
Flange	0.06 mΩ	Jam nut	0.04 mΩ
Body	0.05 mΩ	Coupling nut	0.15 mΩ
Backshell	0.09 mΩ	Backshell	0.22 mΩ
J12 to P12 Backshell-to-backshell	0.23 mΩ		
J13 to Bracket		P13 to Bracket	
Flange	0.39 mΩ	Mounting screw	0.96 mΩ
Body	0.85 mΩ	Coupling nut	1.27 mΩ
Backshell	0.90 mΩ	Backshell	1.24 mΩ
J13 to P13 Backshell-to-backshell	0.44 mΩ		
J14 to Bracket		P14 to Bracket	
Flange	0.07 mΩ	Jam nut	0.15 mΩ
Body	0.28 mΩ	Coupling nut	0.61 mΩ
Backshell	0.29 mΩ	Backshell	0.51 mΩ
J14 to P14 Backshell-to-backshell	0.66 mΩ		

The plug connectors were de-mated from the receptacles for inspection. Images were taken of the receptacle and plug side of the mounting bracket. These are shown in figures 10–12. As can be seen in the images, some salt spray had entered the threaded interface of the coupling nut on two connectors but did not reach the insert of the connector area. The connector socket phenolic was clean as well as the pin interfacial seal. No salt was visible on any of the pin contacts. The environmental sealing characteristics of the connectors performed as designed by keeping the salt spray from entering the pin/contact area. Images of the alodined aluminum bracket are shown in figures 13 and 14. As expected, some corrosive attack was present in areas where the alodined surface had been damaged and removed. However, the pitting found was not sufficiently deep or numerous to affect structural strength or electrical bonding.



(a)

(b)

Figure 10. Overall view of the plug and receptacle sides of the bracket: (a) Receptacles from the plug side of the bracket after the plugs were de-mated and (b) receptacle side view of the bracket with receptacle J13 removed.

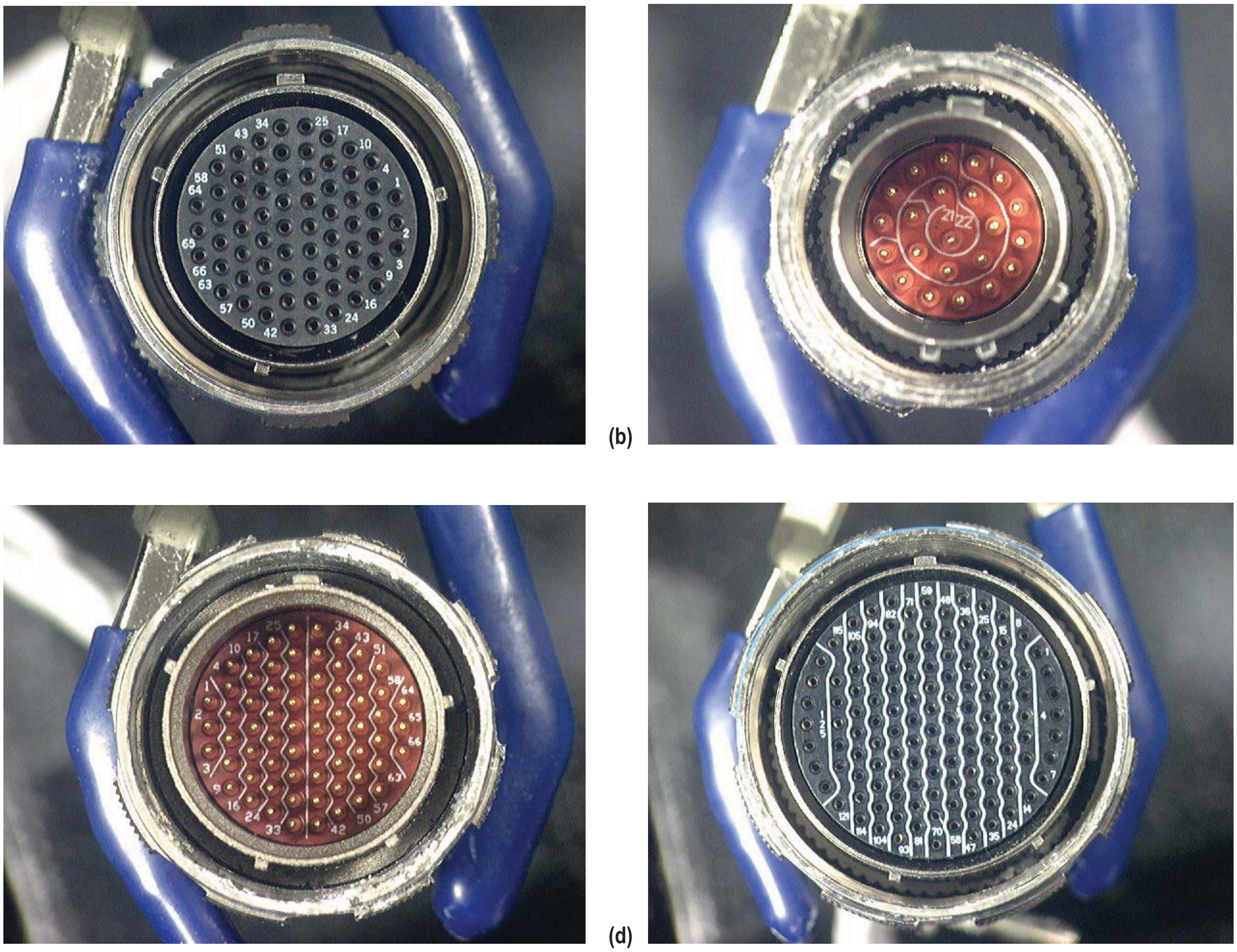


Figure 11. Close-up views of each of the four plugs after de-mating from the receptacle connector: (a) P11, (b) P12, (c) P13, and (d) P14. At this point, the external surface had been cleaned. The sealing characteristics of the connectors performed as designed by keeping the salt spray from entering the pin/contact area. There was no presence of salt on the inside surfaces.

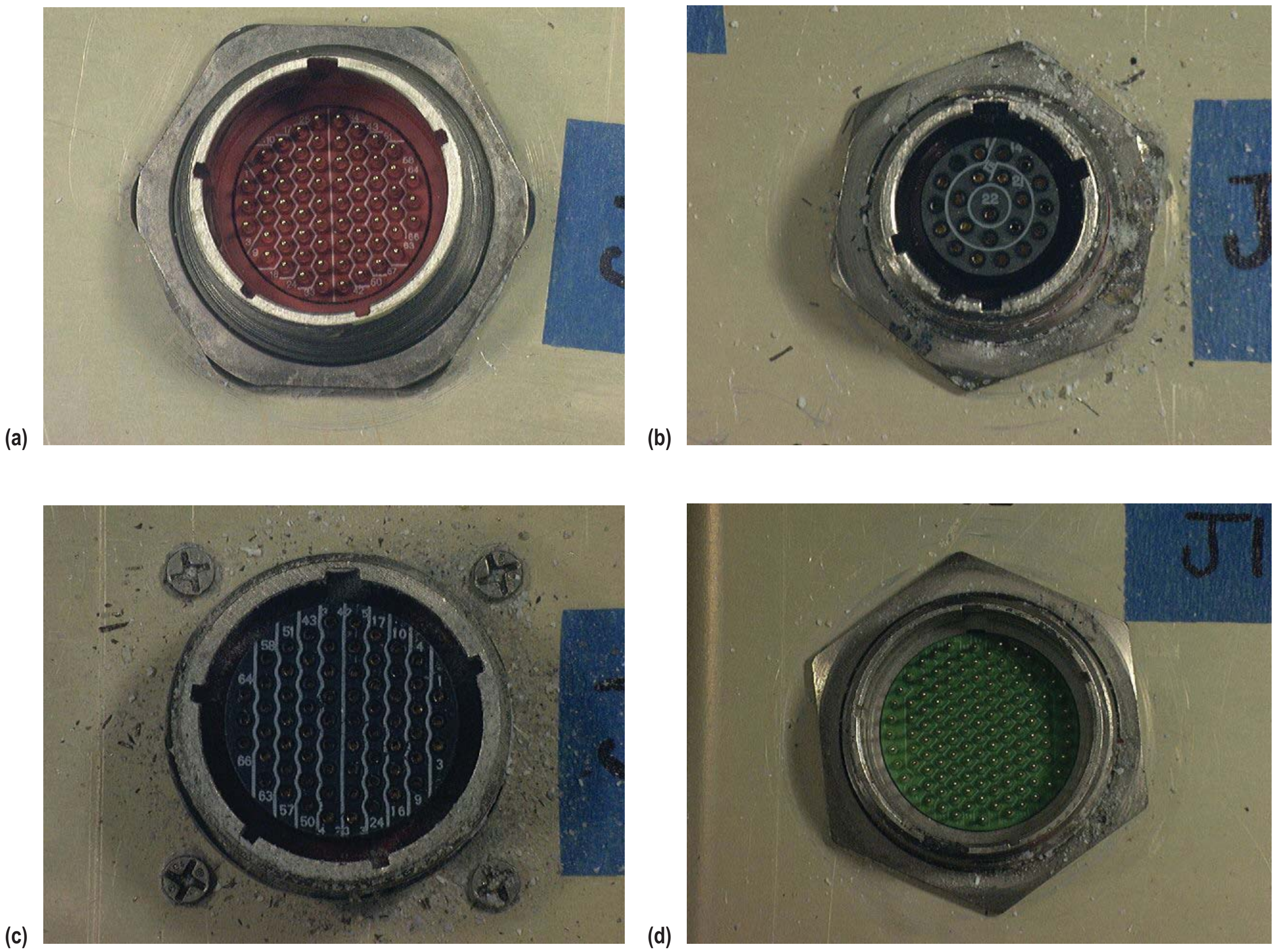


Figure 12. Close-up views of each of the four receptacles after the plugs were de-mated: (a) J11, (b) J12, (c) J13, and (d) J14. The sealing characteristics of the connectors performed as designed by keeping salt from entering the pin/contact area.

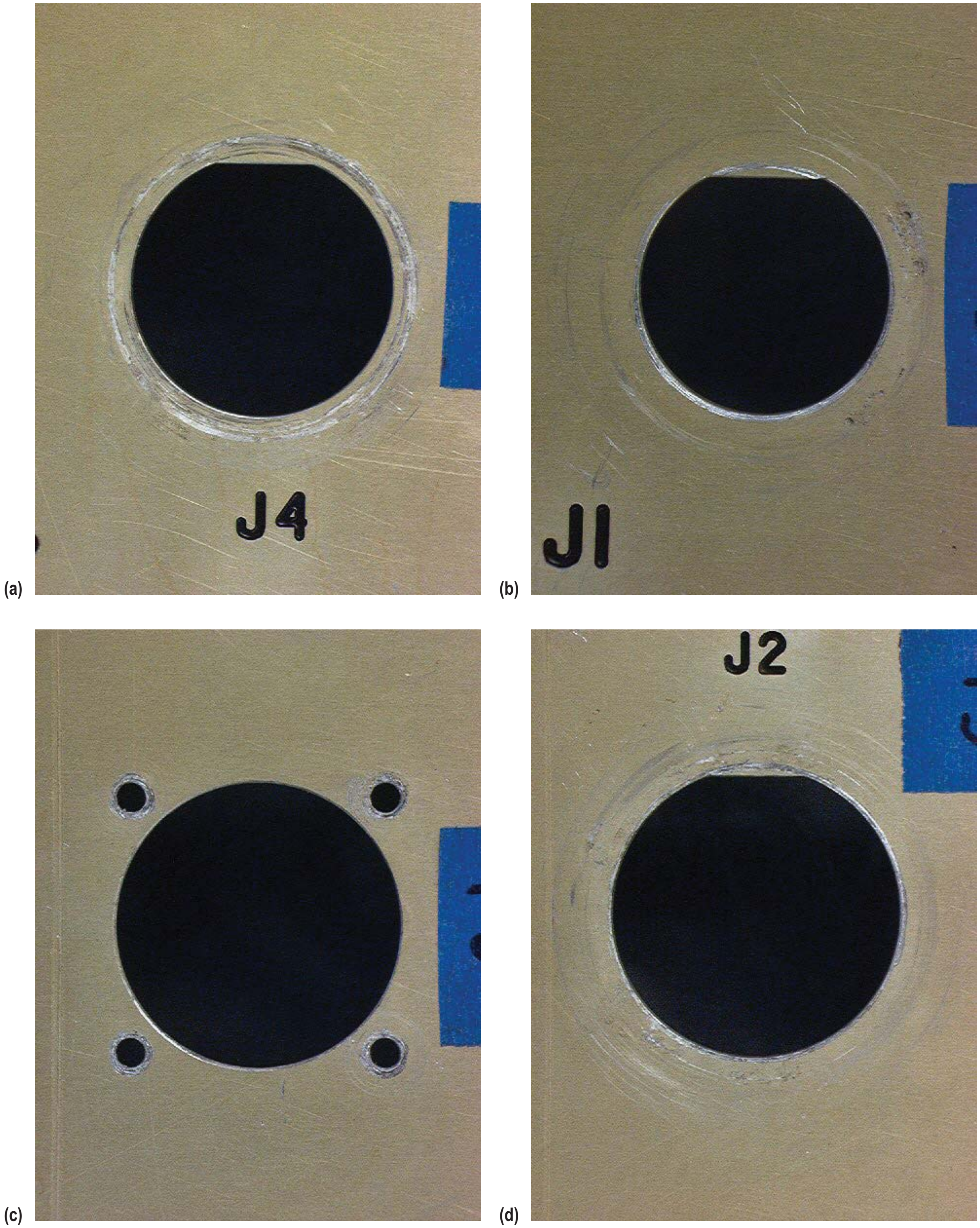
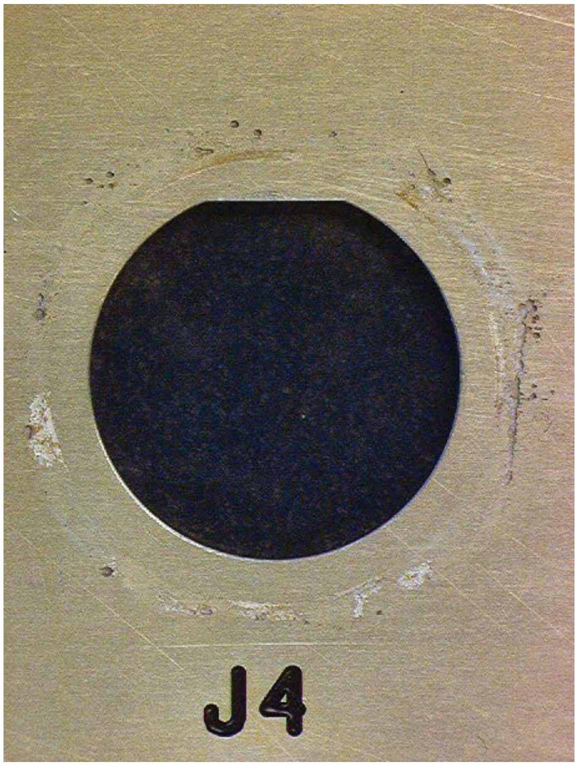
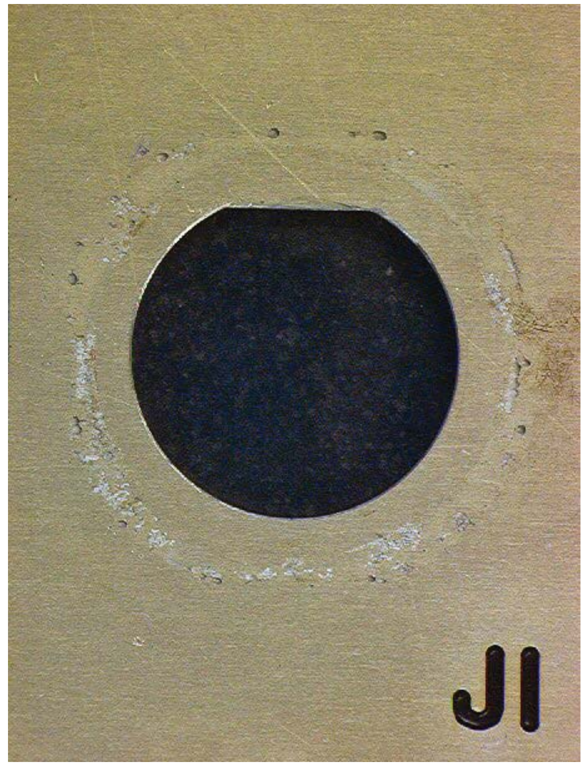


Figure 13. Condition of the plug side of the alodined bracket: (a) Plug side P11, (b) plug side P12 (the only interface on this side that exhibited pitting), (c) plug side P13, and (d) plug side P14.



(a)



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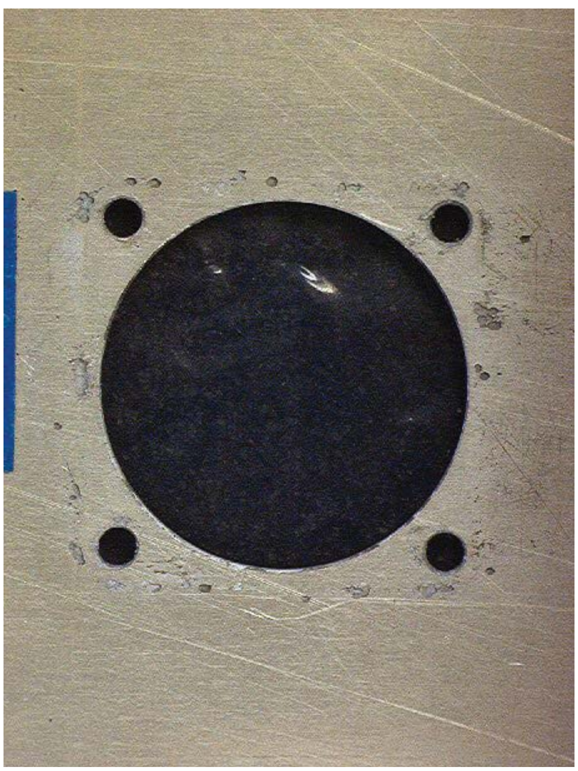
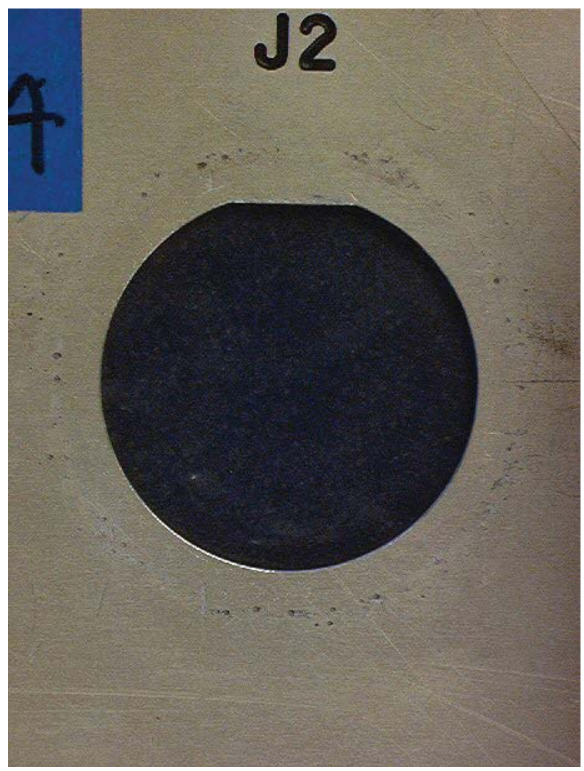


(c)



(d)

Figure 14. Condition of the receptacle flange side of the alodined bracket. This side exhibited some pitting in the flange contact area which did not affect electrical bonding: (a) Receptacle side J11, (b) receptacle side J12, (c) receptacle side J13, and (d) receptacle side J14.

Scanning electron microscopy (SEM) was used to look at the corroded areas on the plugs and receptacles to determine the level of pitting and/or flaking. Examples are shown in figure 15. In these examples, the largest pits found were on plug P12 and the jam nut on connector J12, but they had no effect on jam nut removal. Pitting and flaking were expected on the jam nuts and thread interfaces due to plating damage at installation; however, these spots did not affect connector mating, electrical bonding, or structural integrity. Corrosion found on plug and receptacle bodies was present but typically superficial and spatially limited.

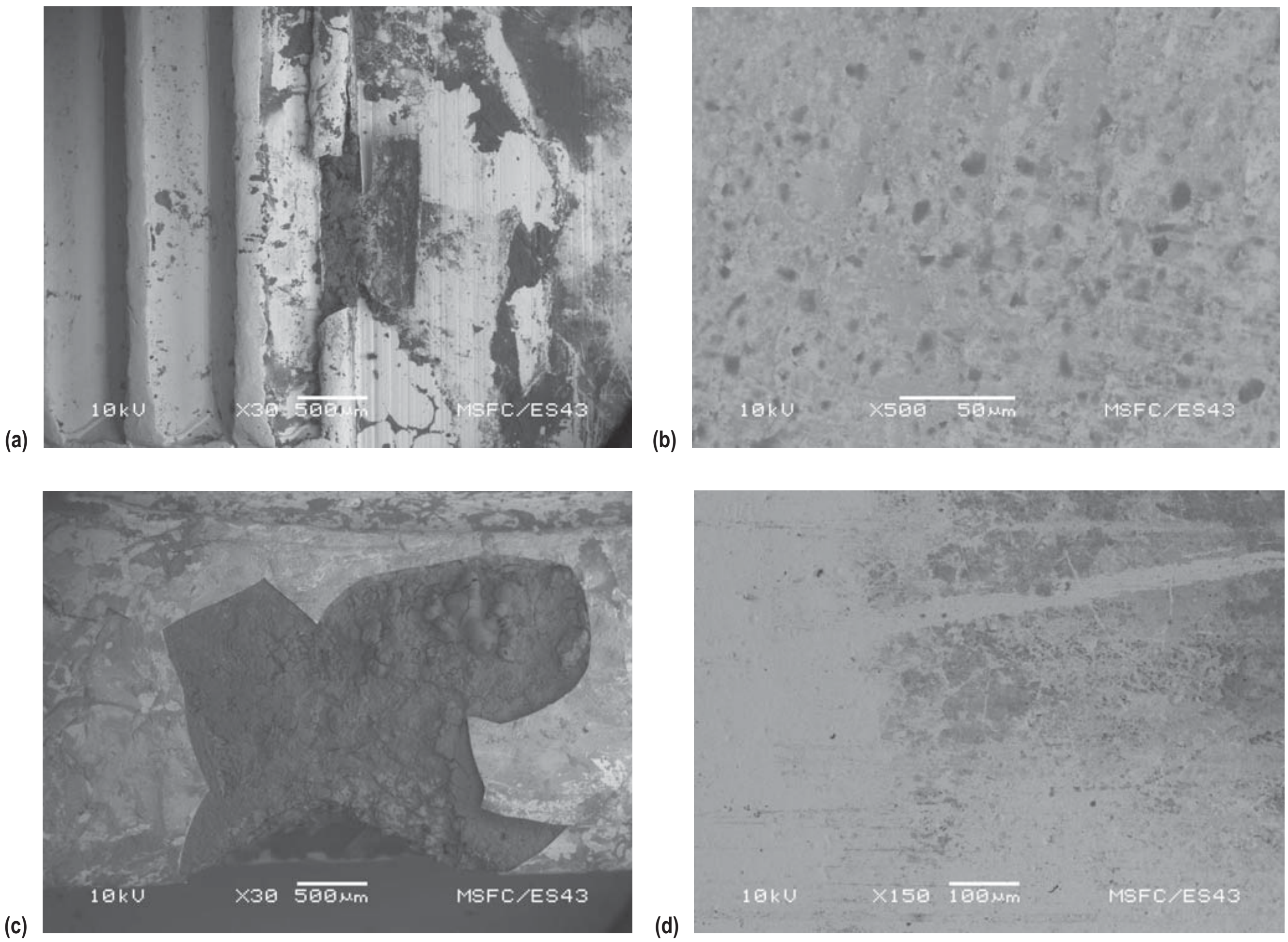


Figure 15. SEM images showing condition of various EN surfaces after exposure, washing, and storage in ambient conditions after several days: (a) Plug P12, (b) corroded area on J12, (c) small area of the jam nut from J12, and (d) superficial corrosion on plug P14.

4. CONCLUSIONS

In conclusion, the MIL-DTL-38999[3] series III, class F, EN-coated aluminum connectors that were subjected to a 168-hr salt spray test passed the NASA-STD-4003A class R bonding resistance requirement of <2.5 mΩ.[6] The test verified that when using MIL-DTL-38999[3] class F, EN-coated aluminum connectors installed into an alodined aluminum bracket per specifications, electrical performance is not degraded outside current specifications. In addition, optical and SEM inspections did not show sufficient pitting or flaking to cause mechanical degradation of the connectors.

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14. ABSTRACT
During preliminary vehicle design reviews, requests were made to change flight termination systems from an electroless nickel (EN) connector coating to a zinc-nickel (ZN) plating. The reason for these changes was due to a new NASA-STD-6012 corrosion requirement where connectors must meet the performance requirement of 168 hr of exposure to salt spray. The specification for class F connectors, MIL-DTL-38999, certifies the EN coating will meet a 48-hr salt spray test, whereas the ZN is certified to meet a 168-hr salt spray test. The ZN finish is a concern because Marshall Space Flight Center has no flight experience with ZN-finished connectors, and MSFC-STD-3012 indicates that zinc and zinc alloys should not be used. The purpose of this test was to run a 168-hr salt spray test to verify the electrical and mechanical integrity of the EN connectors and officially document the results. The salt spray test was conducted per ASTM B117 on several MIL-DTL-38999 flight-like connectors mounted to an aluminum 6061-T6 bracket that was alodined. The configuration, mounting techniques, electrical checks, and materials used were typical of flight and ground support equipment.

15. SUBJECT TERMS
salt fog, salt spray, corrosion, electroless nickel, zinc-nickel, connectors, electrical performance

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